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Estimation of Land Production and Its Response to Cultivated Land Conversion in North China Plain

JIANG Qun′ou[1, 2], DENG Xiangzheng[1, 3], ZHAN Jinyan[4], HE Shujin[1]

(*1. Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China; 2. Graduate University of Chinese Academy of Sciences, Beijing 100049, China; 3. Center for Chinese Agricultural Policy, Chinese Academy of Sciences, Beijing 100101, China; 4. State Key Laboratory of Water Environment Simulation, School of Environment, Beijing Normal University, Beijing 100875, China*)

Abstract: Food safety and its related influencing factors in China are the hot research topics currently, and cultivated land conversion is one of the significant factors influencing food safety in China. Taking the North China Plain as the study area, this paper examines the changes of cultivated land area using satellite images, estimates land productivity from 1985 to 2005 using the model of Estimation System for Land Productivity (ESLP), and analyzes the impact of cultivated land conversion on the land production. Compared with the grain yield data from statistical yearbooks, the results indicate that ESLP model is an effective tool for estimating land productivity. Land productivity in the North China Plain showed a slight decreasing trend from 1985 to 2005, spatially, increased from the north to the south gradually, and the net changes varied in different areas. Cultivated land area recorded a marginal decrease of 8.0×10^5 ha, mainly converted to other land uses. Cultivated land conversion had more significant negative impacts on land production than land productivity did. Land production decreased by about 6.48×10^6 t caused by cultivated land conversion between 1985 and 2005, accounting for 91.9% of the total land production reduction. Although the land productivity increased in Anhui and Jiangsu provinces, it can not offset the overall adverse effects caused by cultivated land conversion. Therefore, there are significant meanings to control the cultivated land conversion and improve the land productivity for ensuring the land production in the North China Plain.

Keywords: land productivity; land production; cultivated land; cultivated land conversion; North China Plain

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1 Introduction

China is a fast-developing country with a large population and relatively limited cultivated land, and land production is an important issue that always plagues the national economy and livelihood of citizens (Ball *et al.*, 1997; de Koning *et al.*, 1999; Deng *et al.*, 2008). In the context of the global food safety crisis being increasingly prominent, the debate on *Who will Feed China* has become a focus of the world. With the rapid increase of population and development of urbanization, the growing demand for resources, especially for cultivated land resources, has led to the conversions among different land uses. The structural change and pattern succession of the land system will undoubtedly lead to changes in suitability and quality of land, and directly influence land productivity (Gao and Deng, 2002; Deng *et al.*, 2006). To ensure food security, China has formulated a national policy that a minimum of 1.8×10^9 mu (1.2×10^9 ha) of cultivated land must be available. The problem of land resource waste has also generated widespread concerns from the government and society. As a result, the structural change of land system and the change of land production resulting from land use con-

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Corresponding author: DENG Xiangzheng. E-mail: dengxz.ccap@igsnrr.ac.cn

versions have become one of the most popular topics in the current academic field (Rozelle and Rosegrant, 1997; Jacoby and Minten, 2006).

In China, many scientists are devoted to exploring crop potential productivity due to the need for agricultural modernization (Yu and Zhao, 1982; Tang, 1997; Gao *et al.*, 2004; Yan *et al.*, 2009). Especially with population growth and urban land expansion leading to cultivated land loss and environment degradation, the increase of grain production is increasingly vital, prompting an urgent need for the raise of agricultural production (Seto *et al.*, 2000; Deng, 2008a). To meet this requirement, crucial steps are to make use of the existing land resources and improve land productivity (a measurement of land production per unit area) as well as control the population growth and expansion of non-agricultural land (Fischer *et al.*, 2005). The two approaches to enhance land production are to increase the multiple crop indices and improve the land productivity. The estimation of land productivity could indicate the possible productivity of the agricultural land or specific crops at certain climate, soil, and agricultural technique levels, and the results will provide the scientific basis for estimating the population-supporting capacity of land, formulating the national or regional agricultural development plan, and determining the investment direction (Fischer *et al.*, 2005). Therefore, the estimation of land production associated with land use conversion is significant for both the theoretical discussion and practical application (Frolking *et al.*, 1999).

This paper takes the North China Plain as the study area to estimate its land productivity from 1985 to 2005 using the model of Estimation System for Land Productivity (ESLP), then analyses the land production changes caused by cultivated land conversion. The robust of the ESLP model is testified to indicate that ESLP is an effective approach to predict the changes of land productivity in the future scenarios. The results of the research on land productivity estimation and land production changes caused by cultivated land conversion can provide decision support information for land-use planning and land resources management.

2 Data and Methods

2.1 Study area

The North China Plain (32°08′–40°16′N, 112°10′–122°40′E) is one of the most significant grain production regions in China (Fig. 1). It covers Tianjin Municipality, Shandong Province, and part of Beijing Municipality, Hebei, Henan, Anhui and Jiangsu provinces, which is the largest alluvial plain of the eastern Asia. As estimated by the remote sensing data derived from the Landsat TM and ETM+ images acquired in 2005, cultivated land area accounts for 79.5% of the total land area of the North China Plain. With a semi-arid to semi-humid warm temperate climate, average annual temperature of 10℃–15℃, and annual precipitation of 500–800 mm, it is evident that the North China Plain is suitable for developing rain-fed agriculture and planting a variety of crops and fruit trees. Meanwhile, it is conducive to mechanization and irrigation with its natural conditions of a flat terrain, deep soil and contiguous land concentration. All of these unique conditions have made the North China Plain a major agricultural region and significant commodity base for grain, cotton, meat and oil.

2.2 Data and processing

2.2.1 Remote sensing data

Satellite remote-sensing imagery is one of the most suitable data sources for detecting and monitoring land use changes at the regional and global scales, such as Landsat TM/ETM+ and CBERS images (Carlson and Sanchez-Azofeifa, 1999; Shalaby and Tateishi, 2007; Brink and Eva, 2009; Dewan and Yamaguchi, 2009; Qiao *et al.*, 2009). The land use database used in this study was developed by the Data Center for Resources and Environment Sciences, Chinese Academy of Sciences, which was interpreted from different periods of Landsat TM/ETM+ imageries, and the interpretation accuracy is as high as 92.5% (Liu *et al.*, 2005). There are four time phases of land use data in the database: 1) the mid-1980s, derived from the Landsat TM images acquired between 1984 and 1989; 2) the mid-1990s, derived from the Landsat TM/ETM+ images between 1995 and 1996; 3) the early-2000s, based on the Landsat TM/ETM+ data acquired between 1999 and 2000; and 4) the mid-2000s, based on the Landsat TM/ETM+ data acquired between 2004 and 2005. In the database, a hierarchical classification system of 25 land use classes was used. In this study, we further grouped 25 classes into 6 classes for brevity: cultivated land, forest land, grassland, water area, built-up land, and unused land (Fig. 1).

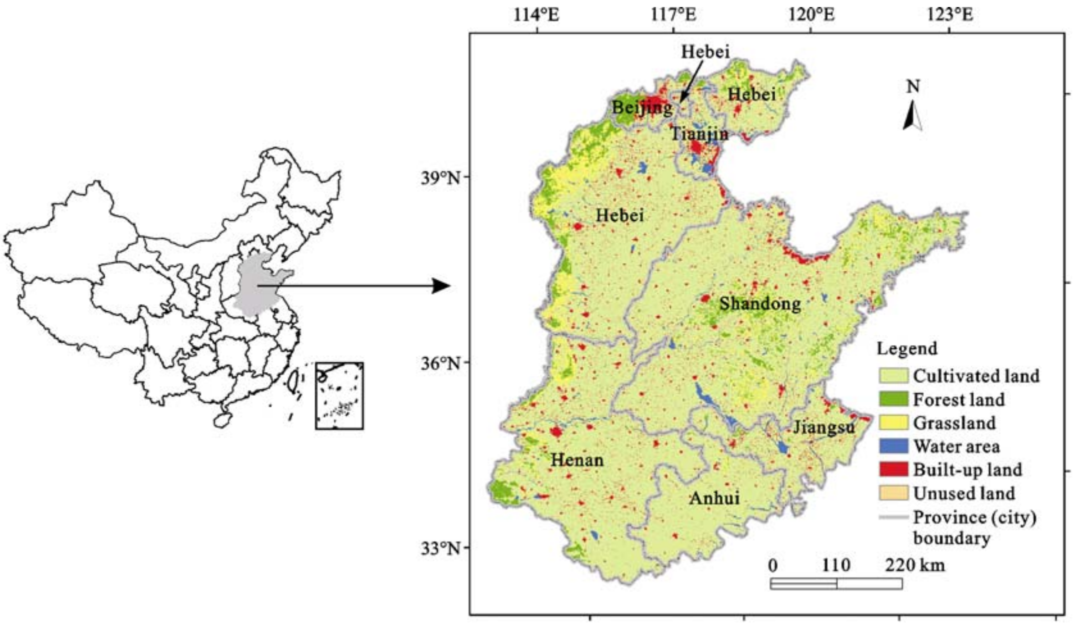


Fig. 1 Location and land use of North China Plain

2.2.2 Climate data

Climate data were derived from the daily records of 117 observation stations maintained by the China Meteorological Administration, covering entire area of the North China Plain from 1985 to 2005. Mean monthly data were calculated based on the daily records, including air temperature, minimum temperature, maximum temperature, precipitation, wind speed, solar radiation, and relative humidity.

A spline interpolation using the coupling-fitted thin-plate interpolation method was chosen to interpolate the meteorological data (Hutchinson and Gessler, 1994). Based on the climatic dependence on topography, climatic variables were interpolated with spatial resolution of 1 km between 1985 and 2005 (Deng, 2008a; 2008b). At a broader scale, temperature declines roughly with the increasing elevation at a typical standard lapse rate of 6.5℃ per 1 km (Hancock and Hutchinson, 2006), so the interpolated air temperature data were adjusted to sea level according to the altitudinal correction factors calculated based on the digital elevation model (DEM) dataset.

2.2.3 Other data

Other datasets that are closely related to land productivity include the measurement of the geophysical and socioeconomic data. In this paper, geographic information including elevation, average slope, percentage of plain area and aspect, were derived from China's Digital Elevation Model Dataset supplied by the National Geomatics Center of China. The soil data were mainly from the survey results of the second national soil census and Soil Map of the People's Republic of China at the scale of 1∶1 000 000 (National Soil Survey Office, 1995). The socioeconomic data were acquired from socioeconomic statistical yearbooks at county level in China from 1985 to 2005 (National Statistical Bureau of China, 1986–2006).

2.3 Methods

2.3.1 ESLP model

The Estimation System for Land Productivity (ESLP) model (Fig. 2) is a collection of application programs, which include the land suitability assessment and land productivity evaluation as well as some advanced applications with the stock of land resources as the fundamental input information (Deng, 2008a). The output of ESLP includes the agro-ecological zoning map, land suitability assessment map, and attribute data, such as crop sown area and crop production. These results provide the basic decision-making information for the assessment of land degradation, simulation of land productivity, and evaluation of land carrying capacity and optimal uses of land resources.

Using the land use information combined with relevant ecological parameters, a complete database can be built by superimposing land ownership, land use conditions, land suitability, the nutritional characteristics of host population and livestock, ground production facilities, and the cost of crop on the agro-ecological zones, which can be used to estimate the land productivity at pixel level.

The core modules of ESLP model include the estimation of cumulative amount of land resources, determination of the land use types and land-use intensity, assessment of the land suitability, the demand of crop growth for climatic resources such as radiation, temperature and precipitation. The substitutability of land use type and crop-type multi-objective planning methods are also encapsulated into the ESLP model. In addition, information of input and management are loaded into the operating parameters of ESLP to form an open and scalable assistant decision system which integrates the approach of eco-economic planning and can be applied to the management of sustainable agriculture.

ESLP adopts the Cobb-Douglas function to estimate land productivity influenced by basic inputs and conventional inputs of agricultural production.

$$Y = AK_1^{\alpha}K_2^{\beta}Y_L^{\gamma} \tag{1}$$

where Y is the land productivity (kg/ha); A is the scale parameter of the Cobb-Douglas function; K_1 is the basic inputs for improving land productivity (yuan (RMB)/ha);

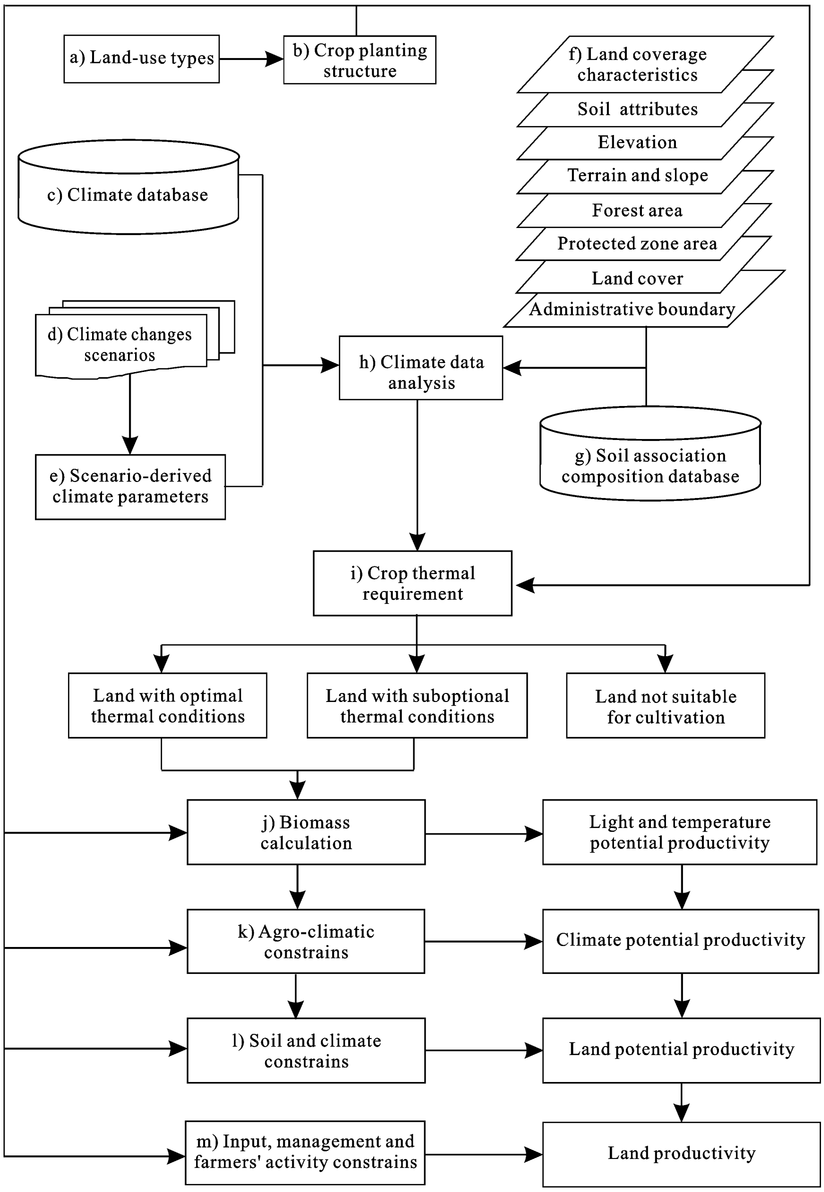
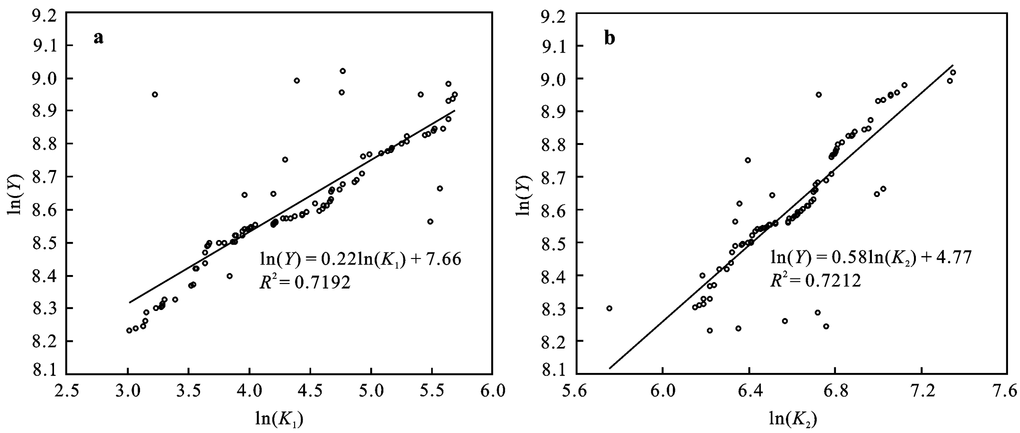


Fig. 2 Flowchart of ESLP model for estimation of land productivity



Data used are chosen from 90 counties randomly located in North China Plain

Fig. 3 Estimated elasticity coefficients of land productivity for basic inputs (a) and conventional inputs (b)

K_2 refers to the conventional inputs to maintain routine agricultural activities (yuan (RMB)/ha); Y_L is the land potential productivity whose specific calculation refers to Deng *et al.* (2009); α, β and γ are the elasticity coefficients of K_1, K_2 and Y_L, respectively. Generally, land productivity increases with the increase of both basic inputs and conventional inputs of land production. Figure 3 shows the relationships between land productivity and these two inputs. The elasticity coefficients for K_1 and K_2 are 0.22 and 0.58, respectively, which indicates the influence of conventional inputs on land productivity is more obvious than that of basic inputs for improving the output of land in the North China Plain.

2.3.2 Estimation of impact of cultivated land conversion on land production

To estimate the impact of cultivated land conversion on land production, we apportioned contribution of the major variables influencing land production, including cultivated land area, land productivity and their joint effects.

$$\Delta A = A_2 - A_1$$

$$\Delta P = P_2 - P_1$$

$$\begin{aligned}\Delta AP &= A_2P_2 - A_1P_1\\ &= (A_1 + \Delta A) \times (P_1 + \Delta P) - A_1 \times P_1\\ &= \Delta A \times P_1 + \Delta P \times A_1 + \Delta A \times \Delta P\end{aligned}$$

where A_1 and A_2 are cultivated land area in different years, and ΔA is the change of cultivated land area; P_1 and P_2 are land productivity in different years, and ΔP is the change of land productivity; A_2P_2 and A_1P_1 are the land production in different years.

Based on Equation (2), changes of total land production (ΔAP) could be divided into three parts, which were caused by the change of cultivated land area (ΔA), the change of land productivity (ΔP) and joint effects ($\Delta A \times \Delta P$) of the change of cultivated land area and land productivity.

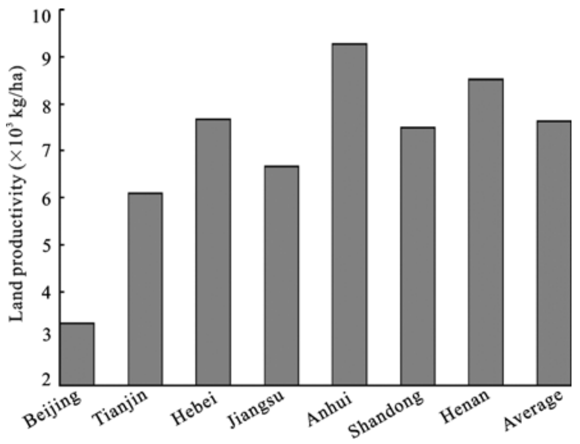
3 Results

3.1 Land productivity between 1985 and 2005

3.1.1 Estimation of land productivity

On the basis of annual data from 1985 to 2005, this paper estimated land productivity in the North China Plain by using ESLP model (Fig. 4). Generally, land productivity was between 3321.8 kg/ha and 9275.1 kg/ha with an average of 7629.2 kg/ha, spatially, declining from the south to the north during the past 20 years in the North China Plain. Anhui Province stood at the highest value (9275.1 kg/ha), 21.6% higher than the average value. The reason may be that it is located in the southern part of warm temperate zone, with excellent sunshine, water and temperature conditions and two-crop system. Beijing was the lowest as typical urbanization, where the cultivated land is often occupied for construction and its development mainly focused on the tertiary industry and education. Cultivated land area of Henan, Hebei and Shandong provinces are the largest, and these provinces are also the major agricultural production regions of the North China Plain, with relatively high land productivity.

Based on the estimated land productivity of different provinces (municipalities) in the North China Plain, this



Provinces (municipalities) included in this study not completely match with corresponding administrative boundaries in China. Except for Shandong and Tianjin which are fully within the North China Plain, Beijing, Henan, Hebei, Jiangsu, and Anhui only parts of their counties or prefectures are delimited in the North China Plain from a view of agro-ecological division in China (Tang, 1997)

Fig. 4 Average annual land productivity from 1985 to 2005

paper analyzed the changes of land productivity from 1985 to 2005 (Fig. 5). Only Jiangsu and Anhui provinces showed an increase trend during the past 20 years. The increase of land productivity in Anhui Province was 6.1 kg/ha, more than that of Jiangsu Province. The highest decrease of land productivity was in Tianjin, as high as 52.1 kg/ha, followed by Hebei Province and Beijing Municipality, whose decreases in land productivity were up to 46.3 kg/ha and 26.0 kg/ha, respectively. The climate changes, especially the decrease of precipitation in the Beijing-Tianjin-Tangshan region, lead to the land productivity reduction. The land productivity of Henan Province had no obvious change, just decreasing by a little amount.

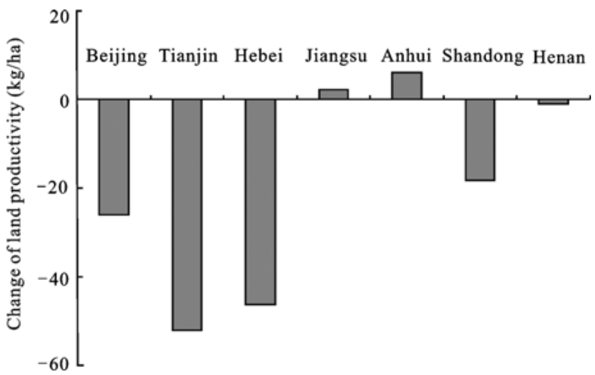


Fig. 5 Change of land productivity in North China Plain from 1985 to 2005

Figure 6 indicated that there existed a slightly decrease of land productivity with the fluctuation in the North China Plain during the past 20 years. The fluctuation in the 1990s was relative violent. For example, the minimum of the land productivity in the North China Plain was around 7547.2 kg/ha in 1997, while the maximum reached 7854.8 kg/ha in 1998. Decrease of land productivity may be caused by the remarkable fluctuation of the precipitation and the drought between 1985 and 2005. The land productivity in 1997 and 1999 was remarkably lower than that in other years because the precipitation decreased by 47% and 43%, respectively, which led to the low land productivity level in the North China Plain.

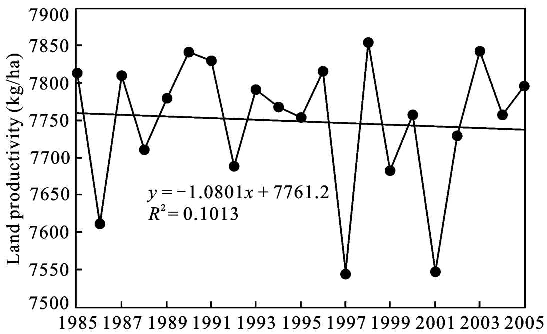


Fig. 6 Annual change of land productivity in North China Plain from 1985 to 2005

3.1.2 Validation of estimated land productivity

The grain yield of the counties in the North China Plain in 2000 was compared with estimated average land productivity at county-level in 2000. By a randomly sampling scheme, 381 counties were chosen to validate the estimation results. The validation results indicated that there was a significant correlation relationship between land productivity estimated by ESLP model and grain yield (R^2 = 0.6432, $p < 0.05$) (Fig. 7). This result illuminated that estimated land productivity by ESLP model in this study can represent agricultural productivity to some extent, and it is feasible to use it to describe the changing trend of land productivity in the North China Plain.

3.2 Impact of cultivated land conversion on land production

3.2.1 Cultivated land conversion

Using the land-use data interpreted from remote sensing images, the cultivated land area in the North China Plain

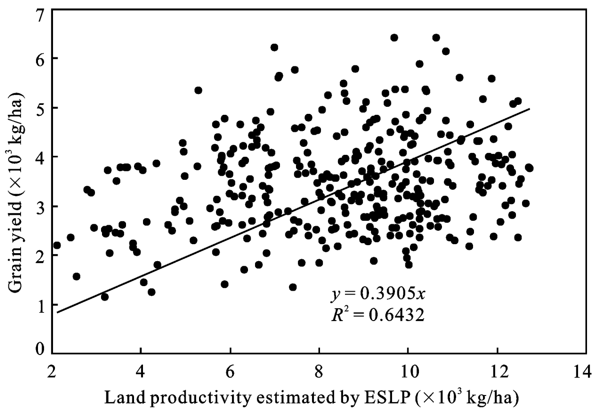


Fig. 7 Relationship between estimated land productivity and grain yield at county level in North China Plain

was estimated. This study only takes the conversion between cultivated land and other land uses into account, but not including the inner conversion in the cultivated land. The results indicated that the total conversion between cultivated land and other land uses was marginal, and showed a slight downward trend in the North China Plain from 1985 to 2005. From 1985 to 2005, cultivated land area converted to other land uses was 8.0×10^5 ha totally, accounting for 2.6% of total cultivated land in 1985 (Table 1). This indicated that annual conversion rate of cultivated land to other land uses was about 0.13% between 1985 and 2005 in the North China Plain.

Analysis of the cultivated land area changes showed that cultivated land area decreased in all the provinces (municipalities) of the North China Plain from 1985 to 2005. The decreasing percentage of cultivated land area in Beijing was the highest, about 27.8%, which revealed the high speed and intensity of urbanization during the past 20 years. That for the rest of the provinces (municipalities) was all below 10%. Estimation results indicated that the cultivated land area in Shandong and Hebei provinces decreased by 2.4×10^5 ha and 2.5×10^5 ha, respectively. As the largest agricultural province in China, cultivated land area of Henan Province decreased slightly, with 0.6×10^5 ha transferred to other land uses, from 1985 to 2005. The decrease of cultivated land area may be mainly due to the expansion of urban and rural construction.

3.2.2 Impact of cultivated land conversion on land production

Land production is affected by multiple factors, and cultivated land conversion is always the significant one. Due to the rapid urbanization in Beijing, Tianjin and other coastal cities, plenty of cultivated lands are transferred to built-up land. Therefore, cultivated land conversion is an important influencing factor of land production in the North China Plain. This study only analyzed two main factors—cultivated land conversion and land productivity due to constraints of research conditions and technical supports. The impact of cultivated land conversion on land production was estimated under the assumption that there were no changes in other conditions, such as climate, soil, level of investment.

The analysis on the spatial distribution of cultivated land showed that the newly reclaimed land was mainly located in the foot area of the Taihang Mountains with low land productivity, while the area of high-yield farmland area in the eastern part reduced significantly. The land production varied in different regions due to the regional heterogeneity of land use change and cultivated land fertility. Although the changing direction and intensity of land productivity featured regional differences in the North China Plain, there was a certain amount of shrinkage of the total land production in all the provinces (municipalities) due to the reduction of cultivated land area primarily. From 1985 to 2005, total

Table 1 Change of cultivated land area in North China Plain between 1985 and 2005

Province (municipality)	Area of cultivated land in 1985 ($\times 10^5$ ha)	Area of cultivated land in 2005 ($\times 10^5$ ha)	Percentage of cultivated land decrease (%)
Beijing	3.6	2.6	27.8
Tianjin	7.0	6.5	7.1
Hebei	72.5	70.0	3.4
Jiangsu	21.3	20.7	2.8
Anhui	30.5	30.1	1.3
Shandong	106.0	103.6	2.3
Henan	69.9	69.3	0.9
North China Plain	310.8	302.8	2.6

land production decreased by 7.05×10^6 t in the North China Plain, of which 91.9% was caused by cultivated land conversion (Table 2). That of Hebei and Shandong provinces decreased more than that of other provinces (municipalities) obviously. Land production reduction of Hebei and Shandong provinces was 2.54×10^6 t and 2.39×10^6 t, respectively, of which 86.6% and 91.6% were due to cultivated land conversion. Although land productivity increased slightly in Jiangsu and Anhui provinces, it failed to offset the decrease of land production caused by cultivated land conversion. In Beijing, a large area of cultivated land conversion caused a significant reduction of land production, which accounted for 19.6% of its total land production in 1985 (Table 2).

Based on Equation (2), the decrease of land production caused by cultivated land conversion and land productivity change was 6.48×10^6 t and 5.5×10^5 t, respectively, and that caused by joint effects was 0.2×10^5 t from 1985 to 2005 in the North China Plain (Table 2). The results indicated that cultivated land conversion had more significant impact on land production than land productivity change in the North China Plain.

4 Discussion and Conclusions

This study estimated land productivity with ESLP model in the North China Plain from 1985 to 2005, and analyzed its spatial-temporal characteristics. Comparison between grain yield and estimated land productivity of the North China Plain in 2000 indicate that ESLP model is an effective method of estimating land productivity. Land productivity was between 3321.8 kg/ha and 9275.1 kg/ha with an average of 7629.2 kg/ha, gradually decreasing from the south to the north in the North China Plain. Average land productivity in Anhui Province was the highest (about 9275.1 kg/ha), however, it was relatively lower in the northern region, such as Beijing and Tianjin. The analysis on the net changes of land productivity from 1985 to 2005 showed that there was an increase in Anhui and Jiangsu provinces, while a decrease in other provinces (municipalities). Land productivity of Tianjin decreased most, followed by Hebei and Beijing. On the whole, land productivity had a slightly decreasing trend with inter-annual fluctuation during the past 20 years in the North China Plain.

Based on the land use data interpreted from the remote sensing images, this study calculated the cultivated land conversion from 1985 to 2005 in the North China Plain. The results showed that the cultivated land area in all the provinces (municipalities) of the North China Plain presented a declining trend, especially in Beijing, which decreased over 27.8% mostly caused by the urbanization. Cultivated land loss of Tianjin was also obvious, with a decrease of 7.1% from 1985 to 2005. The influences of cultivated land conversion on the land production are more obvious than that caused by land productivity. Although the increase of land productivity in some provinces (municipalities) promoted the land production growing, it was outweighed by the negative change caused by cultivated land conversion. The influence of cultivated land conversion and land productivity changes and their interactive influence led to an overall decline in land production of about 7.05×10^6 t, of which 91.9% was caused by cultivated land conversion.

This study analyzed the impact of cultivated land conversion on land production, but some limitations still exist. First, crop growth is a complex process, influenced by many factors in addition to the factors analyzed, such as technological progress, effective labor

Table 2 Changes of land production in North China Plain from 1985 to 2005

Province (municipality)	Land production in 1985 ($\times 10^5$ t)	Change of total land production ($\times 10^5$ t)	Change caused by cultivated land conversion ($\times 10^5$ t)
Beijing	20.4	–4.0	–3.9
Tianjin	52.2	–4.0	–3.6
Hebei	681.5	–25.4	–22.0
Jiangsu	152.0	–3.0	–3.1
Anhui	286.1	–3.1	–3.3
Shandong	851.8	–23.9	–21.9
Henan	638.5	–7.1	–7.0
North China Plain	2682.5	–70.5	–64.8

input and sudden factors like earthquakes, typhoons. Due to constraints on the availability and reliability of this type of data, this study did not analyze these factors. In addition, there may be some factors that have not been realized or some influences can not be explained. To some extent, all of these factors also affect crop growth and land productivity. Therefore, future researches are needed to improve and perfect these elements. Second, estimated impact of cultivated land conversion on land production is based on the assumption that climate, soil conditions, crop types, inputs, management measures and other conditions remain unchanged. However, different types of land conversion in a certain region or its surrounding area actually interact with the crop growth environment affected by soil conditions as well as investment and management levels. These interactions could be analyzed and explored in the future researches.

In this sense, we can conclude that it is necessary to monitor and control cultivated land conversion in order to guarantee regional land production. Meanwhile, increase investments and enhance scientific, technological and management levels are also indispensable for relieving the decreasing land productivity in most areas of the North China plain. The research results could provide decision support information for land use planning and the optimal management of land resources.

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